SPARK

REPORT

STRATEGIC
PLANNING
FOR
APPLIED
RESEARCH
AND
KNOWLEDGE

Science
Council of
British
Columbia

THE B.C. SCIENCE COUNCIL ENERGY SECTORAL PLANNING COMMITTEE REPORT

April 5, 1988

Executive Summary

The Province of B.C., with its wide variety of energy resources and expertise, has a real opportunity to play a significant role in the development of these resources in a way that will spin off new technologies and marketable expertise.

There are several specific opportunities where more planning, effort and financial support would yield considerable benefits. The basic thrust of the committee's recommendations deals with both the resources and the expertise, namely:

1. Significant planning and funding should be put in place to pursue the research into the natural gas vehicle and engine.

2. More money and coherent support should be available for the curiosity driven scientific research into energy. Herein lies the basic training ground for the next generation of experts. A Centre of Excellence for Energy Studies would address many of the present deficiencies in R & D in the Province.

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TABLE OF CONTENTS

1.0 Introduction 1

2.0 Our Energy Sources 2

2.1 Review of the Present Status 2
2.2 New Developments in Exploration, Production and Transportation 4
2.3 Storage and Conversion of Energy 9

3.0 Consumption of Energy 15

3.1 Overview of the Research 15
3.2 Natural Gas as an Alternative Transportation Fuel 18

4.0 Manpower Training 28

5.0 Environmental Considerations 29

6.0 Associated Technologies 30

6.1 Superconductivity 30
6.2 Semiconductors 30
6.3 New Battery Techniques 30
6.4 Fuel Cells 31
6.5 Hydrogen 33

7.0 An Industrial Strategy for B.C. 33

8.0 Recommendations 35

References 39

Appendix A: Canadian Resourcecon Analysis of the Home Compressor Prospects 40

Appendix B: Companies and Organizations Involved in N.G.V. Conversion System Development 44

Appendix C: B.C. Market Analysis for Conservation and Renewable Energy Between 1980 and 1987: EMR 45

1.0. Introduction

Research and Development in Energy should be pursued in B.C. for two major reasons: to exploit the unique opportunties of our various energy resources and to provide the ability for our industries to a) switch to the optimum energy source and b) manufacture and market the technology for and using these energy sources.

"In Canada and in other industrialized countries the dominant source has changed over time, from wood to coal and from coal to oil."[1] We are now into an era where a wide variety of sources are competing, especially in the industrial sector. Oil, however, remains dominant in other parts of the economy, especially in transportation.

"The substitution of other transportation fuels for oil continues to pose technological challenges. Examples of potential alternative fuels include methane methanol or ethanol, liquified coal and hydrogen. Given the size of the transportation sector (it accounts for about 25% of all energy use) and its strategic importance, a truly diverse energy system cannot be said to exist until these technological challenges have been overcome".[1]

In the short term emergency measures could help in allowing us to ride out another "oil crisis", but we cannot be as elastic in our response now as we were in 1973. More fundamental long term solutions must be found and the barriers to further limit oil demand are considerable:

a) The demands for all forms of energy, including oil, will increase due to economic growth and demographic changes.

b) New resources of oil are becoming increasingly costly and difficult to find.

c) Many of the least costly substitution and conservation opportunities have already been exploited.

d) There are significant economic and technological limitations to substitute in transportation.[1]

The Province of B.C., with its wide variety of energy resources and energy expertise has a real opportuntity to play a significant role in the transition away from an "oil" economy.

The basic thrust of the committee's recommendation for energy research have a two-fold theme:

a) Significant planning and funding should be put in place to pursue the research into the natural gas vehicle and engine.

b) More money and coherent support should be available for the curiosity driven scientific research into energy. Herein lies the basic training ground for the next generation of experts.

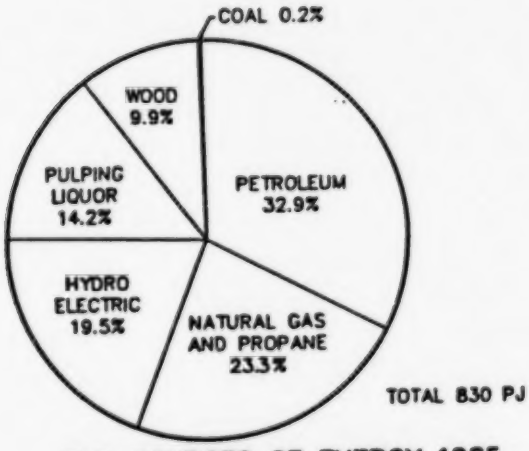
The research success stories for the next decade will be determined by many factors, but it can only happen with well educated scientists and engineers. Economics and politics as well as the new technologies will all have a bearing on the future, so patience, stamina and versatility must be built into the R & D planning.

Full coverage of the energy sector is impossible given the time constraints on this report; however an overview of most aspects is given with an in-depth study of certain selected topics. Section 2 looks at our energy sources; (2.1) the present status of consumption; (2.2) developments in exploration, production and transportation; and (2.3) storage and conversion processes. Section 3 looks at some aspects of how energy is consumed and looks in detail into natural gas as an alternative fuel for engines. Section 4 deals with manpower training and Section 5 with the environment. Section 6 briefly describes some of the new technologies. Section 7 covers some aspects of the management and planning for the future in energy research. The recommendations are summarized in Section 8.

2.0. Our Energy Sources:

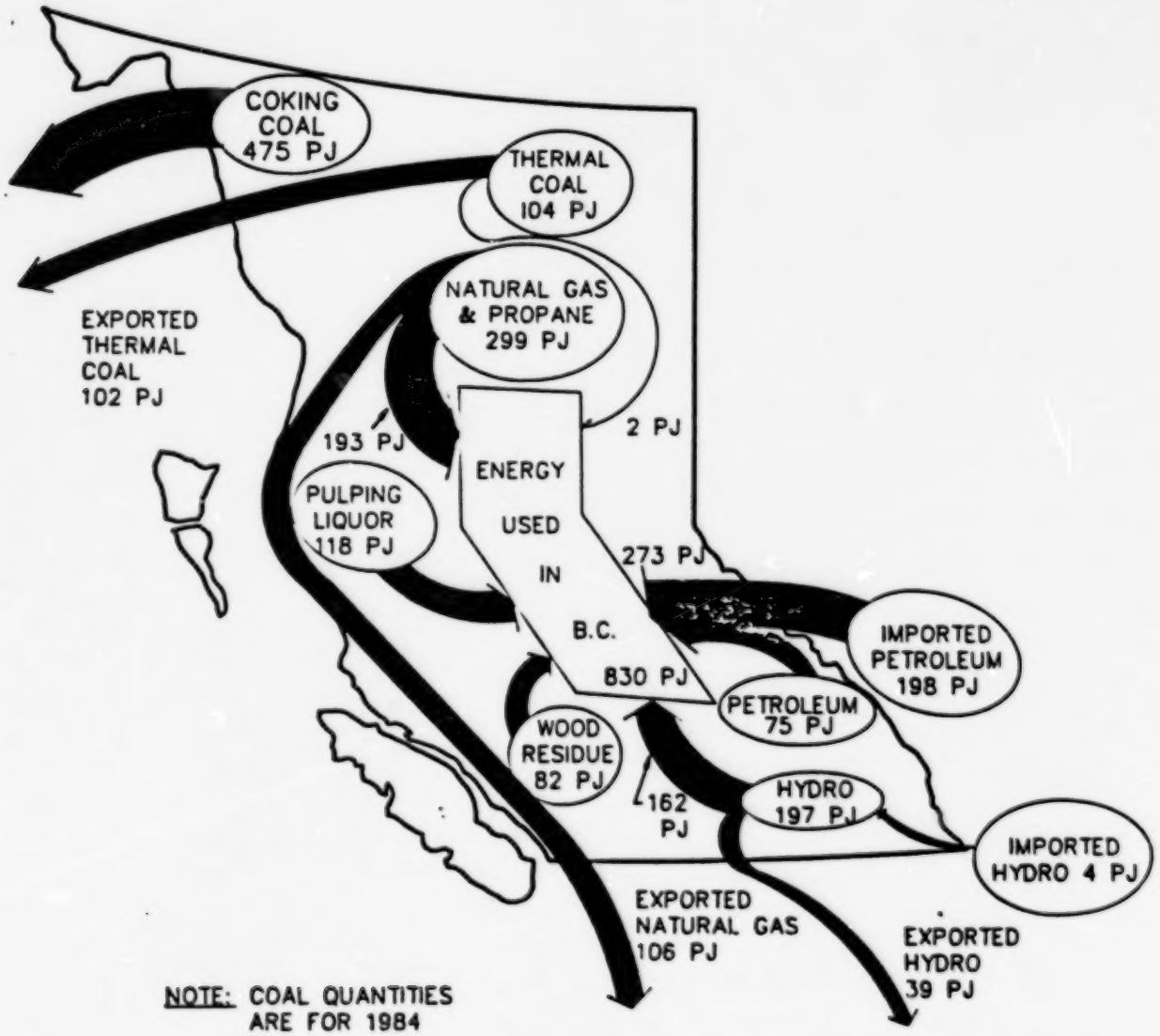
2.1. Review of the Present Status

The sources of energy used in B.C. are approximately as shown in the following graph:



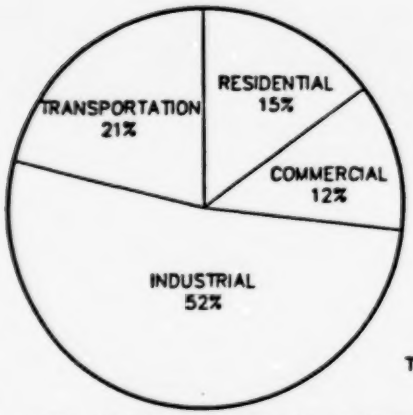
B.C. SOURCES OF ENERGY 1985

The distribution of energy produced by the province, imported into the province and exported from the province is illustrated as follows:



B.C. ENERGY BALANCE 1985

The use of energy within the province is illustrated by the following graph:



B.C. CONSUMPTION OF ENERGY 1985

The total energy presently used amounts to over 830 Peta Joules (PJ) with approximately 23% or 193 PJ being provided by Natural Gas.

Of particular interest to B.C. is its large consumption of petroleum fuel, as it imports approximately 73%. In contrast, B.C. has a large excess of natural gas. The province produces enough for its internal consumption and in addition has enough to export at a much higher rate than the present market will absorb.

The province has extensive resources of both natural gas and of coal. At the present rate of natural gas extraction there are approximately 30 years of remaining established reserves. However it should be pointed out that, historically, new reserves have been found at the same rate as the existing reserves have been used, thereby maintaining a 25 to 30 year reserve cushion. At the present rate of coal production there are 348 years of proven reserves of thermal coal and 96 years of metallurgical coal. At the present rate of production, the remaining established B.C. reserves of petroleum will last approximately 10 years.

2.2. New Developments in Exploration, Production and Transportation

2.2.1. Oil and Gas

New developments in the exploration and production of oil and gas are almost entirely done in secrecy because the system for this resource is highly competitive.

Any development or possible better way to recover or find this resource is heavily guarded in order to provide a better leveraged position when trying to obtain crown lands for the purpose of exploration and development. No company will share their "better" ways of finding or recovering oil or gas with another company, except for a "price".

New developments which would benefit B.C. could include such items as research in products for use in drilling fluids. Wood waste products have been proposed in the past, but to date no known research has been done. In off-shore development the present technology of submersibles should be encouraged since B.C. is leading in several aspects of undersea exploration vehicles.

Ths usage of water for flooding oil field deposits has requirement for large quantities of purified water. The removal of oxygen and bacteria from water is done with equipment usually purchased and manufactured outside of B.C. This latter is very typical of many projects where materials are supplied from outside the province.

The crude deposits discovered in B.C. to date are, on the average, of good quality grade. In essence this means that B.C. does not have any major heavy crude deposits such as the Cold Lake and Tar Sands deposits which require research.

With most oil fields, a good percentage of the oil remains behind after primary and secondary recovery methods are exhausted. Tertiary recovery is often very costly and experimental and it is highly dependent upon the formation of the deposit location. In order to promote tertiary development, governments should seriously consider tax or royalty relief of one type or another to further develop and partially recover the remaining oil in the ground. Government should be open to suggestions by companies to their type of proposals. But a careful cost benefit analysis should be done on a field by field basis before any relief of this sort be granted.

2.2.2. Coal

Few new developments have taken place in exploration, production and transportation of coal in British Columbia during the last several years and there is an enormous amount of work to be done in order to realize opportunities offered by coal in British Columbia. Fortunately, much of the required technology is already available and needs only to be adapted to specific B.C. conditions. The efforts, however, must be undertaken now to ensure the requisite technology is at hand when needed. The timely effort will improve marketability and cost competitiveness of B.C. coals, increase energy self sufficiency, improve the working environment, and reduce the environmental impact of coal development.

It is recognized that some research and development areas identified are long term in relation to current development plans and energy needs. However, the following long term factors can be cited as necessary for ongoing support of research and development: development of local expertise, which may also be marketable as technical or professional services; productive employment of trained graduates; and development of technology in advance of needs to avoid crises in

supply. It may not be opportune for B.C. to engage in all identified areas of coal research and development immediately, but the opportunities may develop later. Consultations with the coal industry will be required for the implementation of coal R & D programs in B.C. As an example, specific projects should be coordinated with existing programs advocated by the Action Committee on Western Canadian Low-Sulfur Coal to Ontario[2], and the soon to be published Coal Association of Canada report.[3]

Coal Resources and Reserves

There is need for better definition and estimation of the province's coal resources and reserves, and for the in-situ determination of the coal's quality. New geophysical exploration methods need to be evaluated and implemented. Strata mechanics and geophysical features of coal bearing formations need to be studied.

Coal Mining

No fundamental changes to mining methods are expected by the year 2000. Development work will be aimed at improving efficiency, productivity, and health and safety. Significant areas of research and development will be hydraulic mining, transportation in the mine, computerization, and automation of mining operations. Different mining methods and equipment will need to be adapted to specific conditions and coal deposits. In addition, the working environment, health and safety, control of methane and dust, environmental concerns and land reclamation must all be addressed.

At present, the land reclamation required is a net cost to mining and is kept to a legally acceptable minimum. Provided that costs are consistent with benefits obtained, improved reclamation techniques could lead to enhanced use of reclaimed land. To accomplish this, research with a broad perspective including coordination of mining-waste disposal-reclamation activities is required. In regard to reclamation techniques, there will be a need for major developments in agronomy at high elevations.

Coal Preparation

There is a growing need for a comprehensive laboratory and pilot plan program to assess preparation characteristics of various coals and the effectiveness of different coal preparation techniques. Research and development is needed in coal beneficiation, coal recovery from fines, dewatering and drying, grinding, refuse utilization and disposal, and in water treatment. A major effort is needed to develop advanced computer controlled coal preparation processes using both physical and chemical methods. Specific research and development programs for the specific coals of interest will be necessary for variable coals with unfavourable washing characteristics. They may include dry cleaning methods, and coal-oil agglomeration.

2.2.3. Hydro-Electricity

Most of the electrical energy generated in British Columbia is produced from hydro resources, which of course is a form of renewable solar energy.

The use of water wheels is one of our oldest sources of energy. Open water wheels were used to grind grain and saw lumber. Some direct mechanical (hydro-mechanical) drives are still used for pulp grinding in B.C.

British Columbia has large hydroelectric resource potential of which about 25% has been developed. Of the remaining 75%, one third or 25% of the total is considered developable. The half that is considered not developable would incur severe environmental impacts, especially on fish.

Large scale hydroelectric sites usually have unique features so that a specific design is required for each site. Hydraulic turbines range from high-head impulse types to low-head variable pitch propeller turbines. The most popular are fixed blade reaction turbines. Designs are usually developed by model tests at an established laboratory. Turbine technology is well developed and the manufacture of turbines is by large heavy manufacturing industries on a world scale. The number of large turbines to be installed in British Columbia between now and the year 2000 is expected to be less than ten units. B.C. Hydro does not expect to add generating capacity to meet its domestic requirements until at least 2000. Requirements in the 1990's will be met by demand side management programs, cogeneration, coordination with other utilities and power purchases.

In non-integrated regions of the province, presently served by diesel engine units, there is an opportunity for small hydroelectric development. The civil design and model testing related to large or small hydroelectric development can be done in British Columbia. There are a number of world class consultants based in B.C. No further major R & D is required to enhance this technology.

Hydro-electricity transportation or simply electrical transmission is by high voltage overhead wires or cables. Because of the remoteness of B.C.'s hydro resources and the limited resources on Vancouver Island, the province has been a leader in this field. B.C. Hydro was a leader in developing 500 kV overhead transmission and the first to install 500 kV A.C. submarine cables. B.C. Rail has one of the highest voltage overhead catenary systems in the world.

Many of the electric utilities in Canada operate their own research and development laboratories. Much of their work involves testing related to regular operations of a utility. Specific research is done to solve operating problems. The Canadian Electrical Association (CEA) with support from EMR and the utilities has a research and development program that coordinates the efforts of Canadian utilities and also interacts with associations in the United States. B.C. Hydro has a large modern research and development facility including a high voltage test laboratory. While there is a need to do research in the hydro electricity field, it is not an attractive one into which research funds could be injected to stimulate economic development in B.C.

The impact of hydroelectric development on fish resources is a major impediment to the optimal development of these resources. Presently there is considerable effort to enhance fish stocks in highly developed rivers such as the Columbia. These enhancement programs should be followed in order to assess whether it is possible to increase the developable hydro-electric potential without loss of fish habitat.

2.2.4. Wood Residue

The production of wood residues in B.C. does not need to be further documented.

Although the idea and technology of pelletizing residue wood is not new, its use has greatly expanded in the last 15 years, especially during the era of very high fossil fuel costs. The concept of pelletizing wood is described below under section 2.3.4. The advantage of pellets is not only that they burn extremely well, but they are very easy to handle, to store, and to transport. Pellets are very dense so that a truck with a given "truck box" volume can carry twice the weight of pellets (and therefore twice the fuel heat quantity) as compared to unpelletized dry wood (not withstanding road load limits).

In addition, pellets flow very nicely so they can be conveyed with simple, economical conveyors and stored in simple silos with the simplest unloading arrangement - a funnel shaped bottom. The handling of pellets contrasts markedly with the handling of normal B.C. hog fuel which is laden with moisture and tends to hang up at every opportunity. On the other hand, the cost of producing hog fuel is miniscule as compared to the high capital and operating cost of manufacturing pellets.

The idea of converting wood to gas and transporting it by pipeline is not presently practicable. The production of the gas is not technically difficult; a number of gassifiers are on the market. It is the cooling and cleaning of the gas which is onerous. As an example, if the gas is cleaned in water scrubbers, the scrubber water treatment plant may be as large and expensive as the gassifier and even more difficult to operate than the gassifier. The resulting wood gas, if produced from dry wood, has approximately 20% of the heat value per cubic meter as compared to natural gas.

2.2.5. Nuclear Energy

The opportunities for activity in the Nuclear Energy area in B.C. consist of Uranium Mining and the use of the Slowpoke reactor as an energy source in remote communities. For the latter the infrastructure for R & D in reactors is so well established in Eastern Canada, there is probably little reason for considering it in B.C. For the former, if a viable mine was found and developed there could be some opportunities for R & D in remote handling and protective devices in the mining operations.

A large scale nuclear plant for the province does not seem to be a viable option for the foreseeable future and even if there was, there would be little if any R & D effort required.

If the technical and cost problems can be resolved, thermo nuclear fusion could represent a long term solution to the world's energy problems. The capital costs are enormous, but there are significant specific areas of materials, plasma and optics research that Canadian and B.C. engineers and scientists can and to some extent, are studying in order to contribute to this effort. Quebec Hydro has the most significant establishment for this research in Canada, but it represents a very small commitment compared to the major activities in Japan, Europe, Russia, and the U.S.A. The Canadian effort is probably barely sufficient to allow us to buy "into" this technology if the breakthrough occurs. Research in selected parts of this discipline should be encouraged in B.C., if for no other reason than to maintain local expertise in this area. The benefits of this technology could outweigh all others.

The spin off from research in this Science and Technology has already produced important economic benefits to the Province. T.I.R. and Vortek Industries are the direct result of "Fusion" research in the Department of Physics at U.B.C.

2.3. Storage and Conversion of Energy From One Form to Another

2.3.1. Oil and Gas

The most important process is in the use of petroleum products or natural gas in thermal electric generating plants. The large capacity units (like Burrard) are used as backup for the hydro-electric system and for energies. The smaller units are used in remote communities where nothing else is available.

For small community power: fuel cells, small nuclear plants, small hydro plants offer real long term alternatives for electricity at costs below those of conventional thermal plants. These ideas are discussed elsewhere in the report.

In spacing heating and industrial heating, the gradual switch from petroleum based fuels to other fuels like natural gas and electricity has significantly reduced the proportion of oil imported to the province.

In residential and building heating, new energy efficient building designs have made considerable inroads into the cost of operation; at the expense, however, of growing environmental concerns about air quality. There is room for more research in heating and ventilating to achieve both energy efficiency and good air quality.

Methanol is an important source of energy for transportation and the technology for synthesizing it from natural gas should not be overlooked. The basic process involves sulphur removal, catalytic steam reforming of natural gas, heat recovery and synthesis of crude methanol in a recirculating synthesis loop. The crude methanol separated out in the loop in fractionated from water to produce a fuel grade product containing less than 0.1% by weight of water. The thermal

efficiency for the process is about 60%. Methanol is not considered to be an economically attractive fuel except as an additive for octane enhancement in gasoline mixtures.[4]

2.3.2. Coal

Coal Transportation, Handling and Storage

Transportation costs are a potential major obstacle to expansion of coal industry in the province. Improvements in transportation are sought in order to minimize these costs. There is a need for lighter cars, faster rail movement, and more efficient loading and unloading. Further research and development in pneumatic and slurry transport, bulk material handling, noise, coal degradation, dust control and coal behaviour during prolonged storage needs to be implemented.

Coal Combustion

Introduction of coal as a fuel for electric power generation and industrial heating and drying, as well as export of thermal coal, will encourage expanded combustion research and development in the Province. Fundamentals of coal combustion need to be studied and new combustion techniques such as fluidized bed combustion and burning of coal-oil and coal-water mixtures need to be developed. Environmental effects of the many contaminants emitted during combustion of coal are not fully understood and will therefore have to be investigated. R & D should center on specific selected coals for specific use, i.e. power generation.

Coal Carbonization

British Columbia is a major exporter of coking coal, and effective technical support of this business through research and development is needed. The work should include characterization of coals for coke making, advanced techniques for making better coke from various coals and their blends, coke degradation, petrographic investigations and fundamentals of coal carbonization. Emission control and other environmental aspects of coke making need continuous research and development. Studies are needed of coal pyrolysis where the yields of gaseous and liquid products are optimized. Furthermore, studies of various uses of carbon products and upgrading of tar should be implemented.

Coal Gasification

Coal gasification is presently not practiced in British Columbia. However, significant benefits would result from developing local expertise in coal gasification even if it is only to put the Province in the position of an informed buyer of technology.

There is a need for research work on coal gasification in order to characterize the properties of British Columbia's coals and to assess their suitability for gasification in various existing and new coal gasification processes. The application of coal gasification to combined cycle and fuel cell power generation is an area which will need to be studied during the next 20 years.

Coal hydrogasification is a new process under development which should be studied in the Province.

Many coal deposits in British Columbia will not be attractive for mining with conventional methods and the potential of underground coal gasification of specific coal seams will need to be investigated. This may involve both field and laboratory work.

"Converted" coal as a future energy source is under serious investigation because of the possibility of an uncontrolled rise in the price of oil. For example (Research & Development, September 1985, p.78), the Electric Power Research Institute committed $25,000,000 for a pilot plant study of a Shell Oil Company coal gasification process.

Coal Liquefaction

British Columbia has a large net deficit in crude oil supply and it could become increasingly desirable for the Province to use coal as a source of liquid fuels. This will require technical and economic studies of various coal liquefaction processes for specific coal deposits. There is a need to establish a core of expertise in the Province in order to support studies of coal liquefaction. Laboratory and pilot plant testing will be needed in order to evaluate the liquefaction potential of B.C. coals and to assess the relative merits of different coal liquefaction processes. Petrographic studies of coals in relation to their ability to liquefy are needed, as are the studies of upgrading of coal liquids into useful products.

While all these coal R & D investigations are valid, the opportunities for economic benefits in the short term are with coal beneficiation and transportation.

Non-Energy Uses of Coal and Other Research

Development of chemical industries based on coal in British Columbia will depend on various economic and political factors, so it is difficult to predict what will happen during the next 20 years. However, the Province should be prepared to meet the challenge when it arises by having a core of people knowledgeable in coal and its various chemical transformations. Therefore it will be necessary to support research and development to broaden the fundamental knowledge of coal structure, its physical properties, chemical forms and its behaviour during chemical transformations. Use of ash residue and mineral waste associated with coal utilization will also require special studies.

The use of the products of petroleum refining as input to petrochemical synthesis is a mature field and research in this area is highly specialized. The potential of coal as a source of peak stock for petrochemical plants could be of substantial interest in B.C. because of the low sulfur content of its coal. However, because of the cost of gasification of coal followed by Fischer-Tropsch synthesis to generate hydrocarbons, this approach to petrochemical production seems unlikely for the near future.

2.3.3. Electricity as a Source

Electricity is a high quality form of energy and can be readily converted to heat, light or mechanical energy. Electricity is easily moved to its source of application and is clean. The main drawback to electricity is that it is difficult to store. It can be stored in capacitors, an application being the electronic flash. It can also be stored in batteries as chemical energy, and this is discussed in Section 6.

Electrolysis can also be used to store electricity (as Hydrogen) but the products are required to go through a thermal cycle in order to convert back to electricity, at considerable loss in efficiency. Specific fuel cell research could improve the conversion efficiency.

Utilities can provide for storage by storing potential hydro energy. This is done by increasing the storage of a dam by raising it and also increasing the size and number of generating units. This provides flexibility in hydroelectric project operation, a form of storage.

When the flexibility of hydroelectric projects has been maximized, a utility may construct a true storage facility. This pumped storage facility has an upper reservoir and motor/generator and pump/turbine units. The motors pump water into the upper reservoir to store energy and when it is required they operate as turbine generators. The overall storage conversion efficiency is over 80%.

As a fuel for transport, electricity is clean but requires an umbilical cord (eg. trolley buses, electric railways). Battery powered vehicles have specialized applications and are limited by battery capacity and weight. One emerging technology that could resolve the conversion of diesel engines to natural gas fuel would be to support research into a natural gas-fuel cell-electric vehicle. This would be a low emission and quiet drive system. Fuel cells are covered in more detail in Section 6.4.

2.3.4. Wood Residue as a Source

Many studies have been done, all over the world, on the subject of utilizing the "forest" residue left in the forest after thinning or after logging. This residue comprises the tops of trees and branches which are too small to saw into lumber or veneer. It can be collected, chipped or hogged, loaded onto trucks and hauled to energy-using plants or to homes and businesses for space heating energy.

This practice has not proven to be economic in B.C. because of the expense of long hauling distances and the cheapness and availability of natural gas. However, in B.C. huge volumes of sawmill residue are used by the sawmills themselves to heat the mills and their lumber drying kilns, and to fuel the power and process boilers in pulpmills. On the coast a huge volume of hog fuel is transported from sawmills to pulpmills via scows; an economical method.

Although the use of "forest residue" has not yet proven economical in B.C. it is utilized in other areas. As an example, in Sweden the "forest residue" is chipped up, loaded on trucks (or tractor-drawn wagons), hauled to wood chip merchants' yards from where it is sold, and delivered to heat using industries and to schools, businesses and homes for space heating. The production and distribution of these "forest residue chips" is well organized and is a sizeable business in Sweden. It was expanded greatly when petroleum fuels, which must be imported by Sweden, were extremely expensive.

Generally the wood residue that is to be used for energy in B.C. is "chipped-up" or "hogged" in a wood crusher (called a hog). At this time the majority of utilized wood residue originates in sawmills and comprises the sawdust and bark produced during the milling of logs into lumber.

Generally the hog fuel is stored in large piles except where surge storage is required by a mill's boiler or thermal-fluid heater and then a storage silo is used with an automated unloading and boiler feeding system.

In several areas of the United States there is a pelletized wood fuel manufacturing and distribution system in place. This system involves the production of wood pellets from residue wood, usually the residue of sawmills or plywood mills. Either the sawmill itself or a second party sets up the pelletizing facility. The pellets are small cylinders of pressed wood. The residue wood has been dried, pulverized and then forced through a steel die to make small cylinders 6mm in diameter by 20mm long, but these can be made larger, up to 12mm by 50mm. These pellets are very dense, almost twice the density of "as grown" dry wood and are very easy to handle. Also because of their high density a large tonnage can be hauled in one truck. These pellets are either sold by the bag, or are sold in bulk and delivered to schools, businesses or homes, which have covered storage bins. These are sold at prices ranging up to $60/ton U.S. ($86/tonne CDN). This price is well above the equivalent price of natural gas in B.C., so this technology awaits the bursting of the gas bubble.

A tremendous amount of research work has been done in the last 20 years on wood gasification. Large scale pilot plant installations have been made and operated with varying rates of success. Most are not now being operated. Wood gasifies very easily and well over one half of the heat from wood is generated from the combustion of its volatiles - the gasification of wood and the subsequent combustion of the gases is an inherent part of the chemical reaction called combustion. However when the wood is gasified and those gases are transported in a pipe for final combustion in a volume type gas burner the problems multiply since the many compounds in the gas tend to agglomerate and/or condense along the way, causing multitudinous operating problems. There is generally no incentive to gasify wood in order to use its energy, since there are many perfectly satisfactory wood furnaces on the market with capacities for heating one room of a house to a size required by a 10-storey high pulp mill power boiler.

If the supply of fossil fuels became severely limited as it did in many places during the Second World War, then it is quite feasible to run transportation equipment (cars, buses, trucks, tractors, etc.) on gasified wood. The wood fuel

can be in the form of chipped-up forest residue, or dry pellets, or hogged sawmill residue, or firewood. In fact, there is a French gasifier on the market which can be purchased and installed on the bed of a pick-up truck, and fuelled with wood chips. The gas is piped to the truck's gasoline engine.

The technology is available to produce methanol or ethanol from wood residue, but at this time the conversion efficiency is poor and the operating cost of this technology is too expensive to make the use of this technology economic in B.C. Sawmills (hundreds of them) have tons of wood residue that is incinerated in "Tee Pee" burners with the energy wasted. The estimated amount of this unused residue in B.C. is 3.7 million oven dried tonnes per annum. The development of a more efficient process for the production of methanol or ethanol could result in the utilization of all of this residue. The market for these alcohol fuels is increasing dramatically as an octane enhancer in automotive gasohol fuel. Therefore the research required to develop a better process could have a very wide use in B.C. and could create a product (an alcohol fuel manufacturing system) for marketing all over the world.

Wood residue is one item in a general class of fuel which is generally called biomass. One of the biomass fuels used widely around the world is municipal waste. B.C. is advancing its use as a source of fuel. The new incinerator-boiler in Burnaby which will supply steam to a manufacturing plant is a good example. A large market exists for a garbage incinerator-boiler for small communities, world-wide. B.C. has many applicable communities which would comprise a good initial market for such a device. B.C. could develop, use, and market a "small community" garbage incinerator.

2.3.5. Solar Energy

Solar energy in the form of photovoltaic cells will not be a major source of electrical energy in the next decade; in fact the EPRI Journal[6] suggests that optimistically 1% of the world's energy needs could be provided by solar energy by the year 2000. The cost in 1984[7] of silicon solar modules was the order of $7.00 to $8.00 (U.S.) per peak watt or perhaps as low as $5.00 per peak watt if bought in megawatt quantities, and the balance of the system charges are less than $2.00 per watt. However, the U.S. Department of Energy has suggested that this price must go down to the order of 70¢ per peak watt before photovoltaics can become competitive with natural gas and oil. Despite the high cost, of course photovoltaics are viable as power sources in remote areas and for devices such as hand held computers, replacing batteries by a permanent source of energy. This type of application could provide a significant business in the very near future. The April 1984 issue of "Renewable Energy" by the Science Council of Canada reports that as of September 1983 there were 1,500 photovoltaic installations in Canada, 400 of which are operated by the Canadian Coast Guard for navigational aids.

There is a continuing interest in solar heating systems around the world. In fact, there are several companies in the Vancouver area which distribute and/or assemble such systems. These systems are used primarily for roof-top style energy sources.

Other forms of solar energy conversion such as photoelectrochemical, helioelectric[8] (focussing the light on a receiver to obtain a very high temperature) and satellite systems are at the present time too expensive to consider.

Wind turbines are the form of "solar" energy which is most close to competing with fossil fuels in terms of energy cost. For example, the August 1983 issue of Bio-Joule[9] reports a cost of 10¢ to 12¢ per kilowatt hour for energy compared to the retail costs currently, the order of 5¢ to 6¢ per kilowatt hour for fossil fuel.

Research and development in the Sciences and Engineering associated with Solar energy continues to yield spin off ideas that are economically interesting. As an example, the process of glazing windows for reflecting solar radiation has developed into at least one local company, Profco (from the SFU Physics Dept.).

3.0. Consumption of Energy

3.1. Overview of the Research

Much of the independent Energy R & D carried out in Canada is aimed at either new ways and/or more efficient ways of storing, converting or consuming energy. There are many government and private organizations funding this work, and to fully categorize these activities goes well beyond the scope of this report.

This section deals with the consumption of energy, i.e. the final end use of the energy, for instance, transportation.

To give some perspective of the R & D opportunities and support offered in the past and the present state of activity; the support provided by EMR and the B.C.Sc.C. will be discussed in detail. These agencies provide funds for all aspects of energy research, but since consumption is the most popular area the information will be presented in this section.

3.1.1. Federal Government Support

Energy Mines and Resources Canada, through several programs, has funded R & D and Demonstration activities in the province on an ongoing basis. EMR also supports R & D through other associations such as ENFOR, CGA, CEA, and others.

The table in Appendix C shows an overview of the possible EMR funding programs available for various technologies and sub-sections in the province. In general R & D funding is administered direct from Ottawa based on requests for proposals that are called yearly. Other activities such as demonstrations and information transfer are administered by the local CREO office.

EMR programs are presently being re-evaluated but it is expected that in general the level of funding will decrease and the emphasis for government support

will move into the information transfer role, the so-called Energy Management and Technology Transfer program (EMTT).

As can be seen from the table, support for R & D has been "across the board" in all sectors and all technologies, but because of this there has been no really intensive focussed support on any one area. This is because conservation measures made a significant impact over a wide range of energy usage.

3.1.2. B.C. Science Council Support

The Walden report gives a very good account of the benefits that the B.C. Science Council research funds have provided to the province.

This present report looks specifically at the R & D in energy from 1980 to 1987. The table 3.1 summarizes the type of research project that the B.C. Science Council has funded since 1980. It is laid out in such a way that each project is categorized in a 2-dimensional matrix with type of energy "source" as the vertical axis and the energy process in mind on the horizontal axis. As an example, a project to convert diesel engines to natural gas would be added to row 3 (Gas) and column 4 (Uses). Over the past 8 years, 18 of the 36 projects surveyed came under uses, and 16 under storage and conversion. Research in solar, electricity and gas were the most popular areas with the uses of natural gas and solar energy the most popular projects.

Table 3.1

B.C. Science Council: Energy R & D Project Categorization

1980 - 1987

	1 Production	2 Storage & Conversion	3 Transp. & Delivery	4 Uses	5 Misc.
1. Oil	-	-	-	-	-
2. Other liquid fuel	-	1	-	1	-
3. Gas	-	1	-	8	-
4. Coal	-	2	-	-	-
5. Solar	-	4	-	5	-
6. Electricity	-	4	2	-	-
7. Wood Residue	-	1	-	2	-
8. Hydrogen	-	2	-	-	-
9. Economic	-	-	-	1	-
10. Miscellaneous	-	1	-	1	-
	0	16	2	18	0

The uses of solar projects ranged from Aquaculture and Agriculture to Solar reflecting materials on windows. The uses of natural gas concentrated on engine conversion units and combustion efficiency with the new fuels.

Significant economic benefits have arisen directly from the support the B.C.Sc.C. was able to give to these projects but on the longer term, new information, education of new scientists and engineers and the upgrading of equipment or processes occurred in all of the projects. It is clear, there are many qualified engineers and scientists scattered throughout industry and the universities who could, given some general direction and more funds and personal support, rise to the challenge of a major R & D thrust in Energy research.

3.2. Natural Gas As An Alternative Transportation Fuel

3.2.1. Introduction

The recommendation is that the B.C. Science Council be open to substantial support of this area of research, based on the following premises:

1) B.C. has large natural gas resources which could be used to reduce Provincial oil imports (which amount to about $700 million per year and are mostly consumed in transportation).

2) There are at the present time specific opportunities for economic conversion of vehicles to natural gas fuelling.

3) Oil prices will rise substantially in the not-too-distant future, making general conversion from gasoline and diesel to natural gas much more attractive financially than at present.

4) B.C. has great need of the new secondary manufacturing industry which could be established here to make, market and export the equipment needed for natural gas distribution and use in vehicles.

5) Fairly substantial commitments to Natural Gas for Vehicles (NGV) have already been made in this province. With substantial continuing support the R & D will give this province a lead in producing the technology for a major shift to substantially increased use of natural gas.

At the present very low world price of oil, conversion of vehicles to natural gas is economic only in selected cases. However it appears that the so-called "oil glut" amounts to a supply-demand imbalance of only about 10 percent, and could quickly disappear with either a quickening of demand (as world economic conditions improve) or a drastic curtailment of supply (due to outbreak of hostilities) or to reimposition of cartel control.

As inexpensive sources of crude oil are gradually depleted, the cost of oil must inevitably rise. This gives B.C., with its large reserves of natural gas, an important opportunity for resource development and for creation of secondary industry.

It may be argued that the recent "oil glut" and the drop in world oil prices have been due in large part to:

i. A world-wide economic recession;

ii. Energy conservation. In the transportation sector the main savings have been due to:

a) smaller cars (perhaps 75%), or

b) more efficient engines and better vehicle aerodynamics (perhaps 25%)

The important point about these measures is that they represent largely non-repeatable gains. When the next oil crisis arises there may be little further savings to be had from these two sources.

Even if hostilities in the Middle East do not lead to another major interruption of supply, the OPEC countries may again be able to impose huge price increases, having shown in the 70's that the demand for oil is highly inelastic. Now that so much has been done to increase the efficiency of vehicular energy consumption, demand has become perhaps even more inelastic.

In Canada we can already see the demand for gasoline and diesel fuel "bottoming out", as these figures of total annual sales indicate:

Gasoline			Diesel		
1982	1984	1986	1982	1984	1986
(megalitres)			(megalitres)		
34,272	32,942	32,853	13,334	14,646	14,901

Diesel fuel sales have risen by about 12% since 1982. The same trends may be expected world-wide as economic conditions improve; it may not be long until the "oil glut" disappears.

There is the risk that if the world economy were to seriously deteriorate, and remain in depression for a long time, world oil prices could stay so low that the benefits of NGV could be long delayed. However this possibility is no argument for not doing the research which would enable this province to flourish when economic conditions improve. Having a real alternative to oil represents an essential insurance policy.

As noted in premises (4) and (5) above, B.C. has potentially a big stake in a shift to NGV. The potential market for NGV conversion is large. Two national projections of future NGV conversion levels are of interest. Energy Mines and Resources Canada has an unofficial target of 50,000 conversions by the end of 1991, and personnel indicate they expect the majority of conversions will be in British Columbia, Ontario and Quebec. The Canadian Gas Association has a forecast of 89,800 conversions by 1992 in its draft five year development plan for the NGV industry. Recent discussions with gas distribution utilities as to their specific plans for NGV promotion suggest the federal target may be somewhat conservative - the CGA forecast a little optimistic. Assuming no dramatic change in price relationships between NGV and gasoline (eg., road tax on NGV or a significant, long term decline in crude oil prices), a target of 75,000 conversions by 1992 is considered reasonable, with most conversion activity likely to be in British Columbia, Ontario and Quebec. In the short term economics will determine how quickly the conversion to natural gas will occur, however in the longer term the

strategic implications of needing a replacement for oil in the transportation sector will be the determining factor.

The appropriateness of an aggressive provincial policy for supporting research in this field in B.C. now follows from:

(i) the scale of possible benefits to the province;
(ii) the indication that this is a field where we could establish a lead without fear of USA or Japanese domination of the field;
(iii) the magnitude of the total effort required to develop and market engine conversion and distribution equipment which will be economic, reliable and safe.
(iv) the risks which small enterprises may not be able to accept without government help and without evidence of coordination of overall development.
(v) the investment in this field which has already been made in this province and the degree of cooperation between industry, researchers and government which already exists.

We turn now to an example of where vehicle conversion to natural gas fuelling would be economical if satisfactory conversion equipment were available.

3.2.2. Conversion of Diesel Truck Fleets to Natural Gas Fuelling

Table 1 provides an analysis of the immediate economic benefit of conversion of large commercial trucks to dual-fuelling with natural gas. The development of conversion equipment with the necessary fuel economy, reliability, safety and emissions control represents an important commercial opportunity for truck fleets and urban buses with adequate access to refuelling stations. An area which has had far too little attention in preliminary work to date is exhaust emmissions. Much more work needs to be done on fuel economy and control, as well as on safety.

A particularly attractive opportunity exists for conversion of open pit mining trucks. Large ore and waste haulers may use in excess of a million litres of diesel annually. Clearly, at this level of fuel consumption, only a small margin between natural gas and diesel prices would be required to justify conversion, and the majority of trucks with access to natural gas should be economic candidates. A demonstration of natural gas fuelling (involving LNG rather than CNG fuel storage) is currently underway at the Crowsnest Resources Line Creek coal mine in southeastern British Columbia. Further conversion system R & D is required to expand the range of engines which can be converted, and to move conversion systems from the prototype stage to the commercial marketplace.

Though with present oil prices the economic margin in favour of NGV for passenger cars is small, a doubling of gasoline price would change the picture completely. Further it should be noted that 30-40% of the total effective price for passenger car gaseous fuelling is accounted for by the cost of equipment to convert the engine from gasoline to NGV. This has large implications for the development of the secondary industry needed for large scale conversion to NGV.

Table 1

CONVERSION OF LARGE COMMERICAL TRUCKS

FROM DIESEL TO DUAL FUELLING WITH NATURAL GAS[5]

(Analysis by Resourcecon)

Characteristics

Engine:	Diesel engine - 350 to 400 HP	
Fuel Efficiency:	45.5 l/100 km	6.2 mpg
Annual Mileage:	175,000 km	108,500 miles
Annual Fuel Consumption:	79,600 litres	17,540 gallons

Equipment Costs (per Vehicle)	Diesel	Diesel/CNG	Diesel/LNG
Fuelling	-	$ 9,370	$40,000
Conversion Kit	-	$10,000	$15,000
- % Import	-	25%	25%
Annualized Costs (¢/litre diesel equivalent)			
Fuel	43.9	29.8	30.0
- Resources	23.0	20.0	n.a.
- Taxes	20.9	9.8	n.a.
Conversion	-	3.4	3.4
- Resources	-	3.2	n.a.
- Taxes	-	0.2	n.a.
Total	43.9	33.2	33.4
- Resources	23.0	23.2	n.a.
- Taxes	20.9	10.0	n.a.

Notes: Taxes include all currently applicable federal and provincial taxes. No provincial road tax is applicable on ATF.
Diesel/CNG and Diesel/LNG energy ratio 35:65.

Notes to Table 1

Equipment Costs:

NGV fuelling costs are capital cost per vehicle of compression, storage and dispensing of natural gas.

Diesel/LNG costs assume a liquefier (plus storage) capable of producing and dispensing the equivalent of 4 million litres per year or diesel fuel.

Conversion costs for dual fuel include the cost of the conversion kit and on-board fuel storage.

Annualized Cost:

Fuel and conversion costs are shown separately, and each cost element is broken down into resources and taxes. Resources refers to the real input involved in producing the fuel or equipment. Taxes include all types of taxes to all levels of government.

The equipment costs related to fuelling are included in the annualized fuel cost and the conversion kit cost in the annualized conversion cost. Annualized conversion costs assume amortization of capital cost at 15 percent, over 5 years for these large commercial trucks.

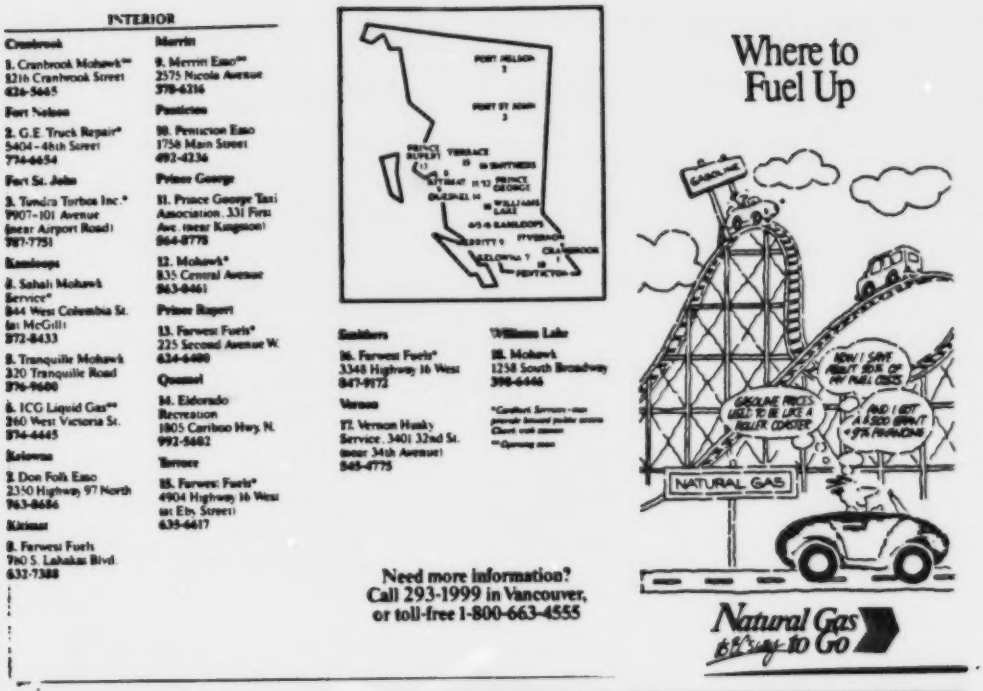
Recognizing the inevitable depletion of petroleum resources, and the need for long term strategy, we proceed to identify research and development needs pertaining to development of a province-wide NGV system.

3.2.3. Natural Gas Distribution for Vehicles

Natural Gas Dispensing Stations

Except for Vancouver Island and remote areas, natural gas is widely available in B.C. Resourcecon[5] points out that "substantial investment in compression storage and dispensing equipment is necessary to transform natural gas to NGV. A typical NGV installation is an add-on to an existing gasoline station and capital costs amount to $250,000 to $300,000. A typical station needs about 250 vehicles filling regularly to be viable. Hence, the compression and related equipment cost per vehicle is roughly $1,000. On the basis of NGV dispensed, the compression and related equipment cost amounts to roughly 6¢ to 7¢ per litre of gasoline equivalent. Refinery margins on gasoline are in the 5¢ to 7¢ per litre range; consequently, the refining cost of gasoline is balanced off by the NGV compression cost".

In the initial stage, NGV marketing suffered from the "chicken and egg" problem. That is, without NGV stations it was difficult to interest the public in conversions, and at the same time it was difficult to convince gasoline retailers to install compression equipment without a base of customers. A combination of Federal government incentives and the involvement of major oil companies has partially overcome this problem, and in British Columbia, and the other major Canadian cities, a basic network of retail NGV outlets now exists." This is shown on figure 3.1 (page following).



INTERIOR

Cranbrook

1. Cranbrook Mohawk**
1216 Cranbrook Street
426-5665

Fort Nelson

2. G.E. Truck Repair*
5404 - 48th Street
774-6654

Fort St. John

3. Tundra Turbos Inc.*
9907 - 101 Avenue
(near Airport Road)
787-7751

Kamloops

4. Sahali Mohawk Service*
844 West Columbia St.
(at McGill)
372-8433

5. Tranquille Mohawk
320 Tranquille Road
376-9600

6. ICG Liquid Gas**
360 West Victoria St.
374-4445

Kelowna

7. Don Folk Esso
2350 Highway 97 North
763-8656

Kitimat

8. Farwest Fuels
780 S. Lahakas Blvd.
632-7388

Merritt

9. Merritt Esso**
2575 Nicola Avenue
378-6216

Penticton

10. Penticton Esso
1756 Main Street
492-4236

Prince George

11. Prince George Taxi Association .331 First Ave. (near Kingston)
564-8778

12. Mohawk*
835 Central Avenue
563-0461

Prince Rupert

13. Farwest Fuels*
225 Second Avenue W.
624-6480

Quesnel

14. Eldorado Recreation
1805 Caribou Hwy. N.
992-5682

Terrace

15. Farwest Fuels*
4904 Highway 16 West
(at Eby Street)
635-6617

Smithers

16. Farwest Fuels*
3348 Highway 16 West
847-9172

Vernon

17. Vernon Husky Service . 3401 32nd St. (near 34th Avenue)
545-4775

Williams Lake

18. Mohawk
1258 South Broadway
398-6446

*Certified Servicenter that provide licensed propane service. Check with station.

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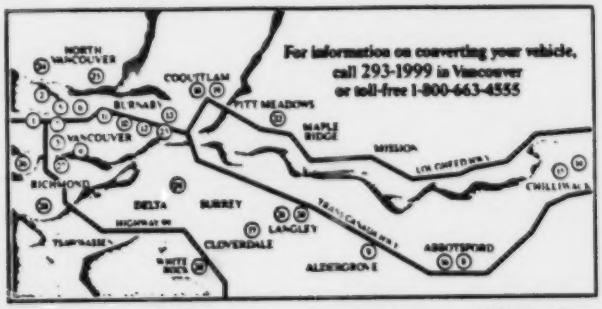

For information on converting your vehicle, call 293-1999 in Vancouver or toll-free 1-800-663-4555

VANCOUVER

1. Arbutus Shell Service
2103 West Broadway
(at Arbutus)
738-7949

2. Beachview Service Ltd
711 Beach Avenue
681-6532

3. Cunningham Husky Service
750 West 70th Avenue
(at Marine Drive)
327-7111

4. Fraserview Fuel Centre Petro-Canada
710 S.E. Marine Drive
(at Fraser)
327-4185

5. Granville Service Petro-Canada
1409 W. 6th Avenue
(at Hemlock)
738-7198

6. Main & Terminal Esso, 1405 Main Street
688-6843

7. Yellow Cab Service
1441 Clark Drive
253-1517

LOWER MAINLAND FRASER VALLEY

Abbotsford

8. Hal's Esso Service
1915 McCallum Road
859-7013

Aldergrove

9. Otter Co-op
3600 - 248 Street
(at Fraser Highway)
856-2517

Burnaby

10. Freeway Shell Service, 4505 Canada Way (at Willingdon)
434-2312

11. John F. Adams & Son Ltd.
3267 Norland Avenue
298-3284

12. National Foulenry Ltd., 7353 - 6th Street (near Edmonds)
526-0333

Burnaby continued

13. North Road Esso Service
3965 North Road
(North Rd. & Austin)
421-6545

Chilliwack

14. East Chilliwack Co-op
46255 Chilliwack Central Road
792-4211

15. ICG Energy Centre
45630 Yale Road
795-9124

Clearbrook

16. Clearbrook Shell
2181 Clearbrook Road
850-1150

Cloverdale

17. Cloverdale Chevron
17790 - 56th Avenue
(at Highway 10)
574-0540

Coquitlam

18. ICG Liquid Gas Ltd. - Fleet Stop
176 Golden Drive
(Mayfair Industrial Park)
464-5040

19. Westwood Shell Service
3051 Lougheed Hwy.
(at Westwood)
464-5656

Langley

20. Happy Face Esso
8590 - 200th Street
(at Highway 1)
888-1844

21. Husky Service
19811 Fraser Highway
(at Highway 10)
530-6323

Maple Ridge

22. Husky Service
21592 Lougheed Hwy.
(at 216th Street)
467-6622

New Westminster

23. Brunette Cardlock Shell Service*
435 Brunette Street
(at Braid Street)
523-0636

North Vancouver

24. Capilano Texaco
1801 Capilano Road
(at Marine)
988-5288

25. Main & Mountain Fuel Centre Petro-Canada
185 Mountain Hwy.
(at Main)
988-8984

Richmond

26. Airport Service Centre Petro-Canada
Vancouver International Airport
273-4544

27. Bridgeport Chevron Service
12011 Bridgeport Road
(at #5 Road)
278-4914

28. Mohawk Airport Service
9060 Bridgeport Road
278-9811

Surrey

29. Surrey Centre Selkirk Shell Service
9900 King George Highway, (at Fraser Highway)
588-2211

White Rock

30. Mountainview Service Petro-Canada
2713 - 152 Street (at King George Highway)
536-2307

*Certified Servicenter that provide licensed propane service. Check with station.

Figure 3.1 B.C. Hydro Pamphlet on Natural Gas Stations in B.C.

Home Compressors

Since natural gas is connected to a very large fraction of homes in the province the possibility of overnight refueling with a small compressor could compensate for the disadvantage of reduced vehicle range (in urban use) with natural gas vs. gasoline fuelling.

Developing a satisfactorily safe and reasonably low cost compressor and dispenser system presents a substantial problem, but considerable work is underway. Appendix A presents the Resourcecon analysis of this possibility.

3.2.4. On-Board Fuel Storage

Compressed Natural Gas (CNG)

The maximum storage pressure of 3,000 psi which has been adopted in Canada implies a fairly massive storage tank as well as considerable volume, for adequate vehicle range. The 3,000 psi rated storage vessel is heavy and expensive. Most storage cylinders in current use weigh about 3.5 to 4.0 kg per litre of gasoline equivalent storage. The two cylinders which would be used in conversion of a typical passenger auto have a (landed, before markup) price of $700 to $1,000.

The traditional CNG storage cylinder is fabricated from steel, and production involves a major, purpose-oriented industrial plant. Most Canadian supply has been sourced from Italy, though a U.S. supplier offers a suitable product. For a period, fiber-wrapped aluminum vessels provided a lighter but more costly alternative to steel cylinders. The actual production facility for aluminum cylinders is relatively inexpensive and involves industrial equipment; however, production requires a supply of large-diameter seamless aluminum tube which is dependent on a very costly press for production. The primary U.S. manufacturer of aluminum cylinders has now terminated operation. Relative to steel cylinders, the small weight advantage but significant cost disadvantage (of aluminum relative to steel) suggests that aluminum cylinders are unlikely to be viable in most transportation applications. Innovation of fiber-winding for aluminum cylinders did provide an opportunity for transfer of the technology to steel cylinders, and two manufacturers now offer fiber-wound steel cylinders, though few are yet in use. This is not, of course, to say that there is not room for further innovation in CNG tank design and fabrication.[5]

Liquefied Natural Gas (LNG)

The rationale for use of liquefied natural gas is that the energy storage density is higher, by a factor of 2.4, than with CNG at 3,000 psi and the storage vessel is at atmosphereic pressure. The disadvantage is that venting of fuel which is maintained at -161°C must be provided, to allow for the consequences of heat leak. Tanks have been built with sufficient thermal insulation to avoid boil-off even with summer ambient temperatures for up to a week or more. Also there is no inherent difficulty in liquefying the natural gas. Resourcecon[5] points out that natural gas liquefaction has been undertaken on a commercial basis since the mid-1960's. Large plants (with capacities to over 1,000,000 Mcf per day) have been

built for seaborne trade in LNG. Smaller facilities (5,000 to 20,000 Mcf per day) are common for peak shaving, i.e. a process whereby natural gas distributors liquefy natural gas during peak periods (summer), in order to increase supply during extended cold periods in the winter. B.C. Hydro operates an LNG plant for this purpose on Tilbury Island. LNG has not been used as a road transportation fuel in a commercial operation.

A system approach to using LNG as a transportation fuel has been developed by a British Columbia company, Cryogas Engineering Ltd. Cryogas has designs for small skid-mounted liquefiers with capacities from 200 to 1,000 Mcf per day, equivalent to 2,500 to 12,000 litres of diesel fuel per day. The concept is that niche markets exist where locally available natural gas can be transformed to LNG and utilized as a road transport fule. Surplus or shut-in gas, at a price which is much lower than the equivalent diesel fuel, could be marketed in this way. In addition to the liquefier, Cryogas has developed dual fuel conversion technology for Cummins engines.

Cryogas has a demonstration unit (50 Mcf per day, equivalent to 600 litres per day of diesel) in operation at the Line Creek coal mine of Crowsnest Resources Ltd., Sparwood, British Columbia. Cryogas is currently promoting a commercial scale operation in northeast British Columbia.

Adsorption Storage of Natural Gas

Adsorption of natural gas on porous materials offers the possibility of enhanced storage density at room temperatures. Resourcecon[5] reports that work at the Royal Military College in Kingston, Ontario is reported to have resulted in identification of a carbon structure which will hold as much gas at 500 psi as a void at 2,000 psi. Additional work is currently underway, but details are confidential. Another project relating to development of adsorbents is expected in favour of natural gas. An important conclusion is that a breakthrough in gas storage would be the basis for a major shift to NGV in countries with surplus natural gas.

The invention of an inexpensive and operationally attractive natural gas storage tank should be a basis for bringing major auto manufacturers into the NGV industry, and result in availability of NGV vehicles at little cost premium to gasoline vehicles. It would greatly extend the range of natural gas vehicles, reduce the weight penalty, and allow engines to be optimized for natural gas operation. The latter development would eliminate power loss currently experienced by spark-ignition vehicles, and would improve energy efficiency and emissions characteristics. With these advances, a major portion of the Canadian new car market should be captured by natural gas vehicles.

3.2.5. Conversion of Spark-Ignition Engines to Natural Gas

For spark-ignition conversion kits, old and inadequate technology has mainly been used (as shown by various vehicle testing programs). Advanced conversion system development eg. the GEN II (generation 2, microprocessor controlled) of CNG systems has apparently been interrupted.

Second generation ("Gen II") conversion systems have reached a prototype stage. They are likely to incorporate microprocessor monitoring and control systems. CNG Fuel Systems of Mississauga had reached a fairly advanced stage with a Gen II prototype, when the company ceased business in 1987. It is likely the technology will be transferred to another player in the field, perhaps with input from the CGA or member utilities. A second Gen II type of conversion system has been developed to an advanced prototype stage by Airsensors Inc. of Seattle. Testing has been conducted by the B.C. Research Council, and it is understood the results were considered very good.

Installation of a conversion system with two steel storage cylinders typically costs about $3,000 at the present time. A breakdown of this cost for an installation in British Columbia is estimated as follows:

Imported equipment (landed cost)	
cylinders	$ 800
regulator, some mixers, ignition module valves, lines, gauges, misc. fittings	525
Domestic equipment including tank brackets, gas bags, some mixers, fittings	
B.C. content	100
other Canadian content	100
Federal sales tax on above	24
Distributor margins	
B.C. or other provinces	450
Installer margin on equipment	350
Installer labour charge	650
TOTAL	$2,999

3.2.6. Conversion of Diesel Engines to Natural Gas

For compression-ignition engines, attempts to convert to dual fuelling (i.e. natural fumigation, or inlet port injection) have produced generally poor part load efficiency, largely unacceptable emissions, and severe problems with detonation and pressure over-loading leading to engine failures. It appears that these problems can only be avoided with a major new development effort on direct injection of natural gas into the engine cylinder coupled with possibly new methods of ignition. Work already done on marine engines in Norway and Japan points the way but little or nothing has been done as yet, for highway or rail transport engines.

It is extremely unfortunate that most road vehicle diesel conversions to date have utilized methods which have high pollutive emissions, because environmental impact (particularly regulation) is the big force in North America today which compels interest in alternative fuels. This interest lies in methanol as well as NGV and in conversions of diesel engines to SI engines optimized for NGV. Emissions regulations pose a critical but surmountable test on the acceptability of alternative fuels for transportation.

Two forms of conversion may be applicable to diesel engines, or the heavy engines for which diesels are normally selected. The first is to modify the diesel engine to natural gas/diesel, with a charge of diesel fuel piloting the ignition of the natural gas. The second is to modify the engine to monofuel natural gas fuelling, with a requirement for a throttle and spark ignition system. While both approaches could apply to either aftermarket retrofits or factory-manufactured engines, it may be appreciated that retrofitting of a dual fuel system to an existing engine is less complex and physically demanding than modification to spark ignition. In constrast, on a routine production basis in a factory, either gas fueling approach could readily be adopted.

Canada and New Zealand are the current leaders in development of natural gas fuelling technology for diesel engines. In the case of dual fuelling, both mechanical and electronic control approaches have been adopted. The mechanical systems probably can be traced back to Italian technology, and usually can be adapted to smaller, naturally aspirated, four-stroke cycle diesels. The drawback for such systems is that easily-convertible engines seldom use enough fuel to make the conversion economic.

For larger, turbocharged diesel engines, the currently favoured conversion approach involves the use of an electronic (microprocessor) system to monitor engine performance and control the volumes of diesel injected and of natural ggas supplied to the air stream above the turbocharger. A primary objective of the control system is to maximize the natural gas component of the fuel mix, but to ensure that detonation (which results from excessive natural gas) is avoided. To date it has been necessary to develop diesel engine conversion systems on a model by model basis. A typical approach involves mapping engine performance (fuel input, cylinder pressures, power output, speed, etc.) on diesel, then determining the maximum possible level of natural gas substitution through the engine's operating range, and devising a control system to monitor engine output and supply an appropriate mixture of diesel and natural gas. In Canada, systems have been developed for various Cummins, Caterpillar and John Deere engines, but none has yet passed a prototype stage. Most developers of these systems envisage that they would ultimately cost under $5,000 (excluding fuel storage), and that installation would involve the relatively minor addition of engine compartment componentry, rather than major physical work on the engine.

To date, Canadian work with spark-ignition systems for heavy-engine applications has been quite limited. Demonstrations are underway on the Ottawa and Hamilton transit systems which involve spark-ignition propane and natural gas fuelling respectively, but these incorporate European replacment engines which have been supplied for the fuels in use. One of the New Zealand companies active in spark-ignition conversions, Transport Fuel Systems, is represented in Canada by International Pressure Control Systems of Vancouver. A Fort St. John company is reported to be converting a Cummins engine with a Transport Fuel system.

British Columbia companies have taken a leading role in the development of natural gas/diesel conversion systems. Several systems may be considered ready for field testing of prototypes. A listing of companies active in the field of conversion system development is included as Appendix B.

The attitude of North America engine manufacturers towards natural gas fuelling of their engines is a subject for consideration. The basic stand of most manufacturers appears to be that they will develop alternative fuelling systems in-house, or at least acquire total control over proprietary fuelling technology they ultimately use. Cooperation between engine manufacturers and ATF system developers has improved during the past five years, but it appears unlikely that any of the major engine manufacturers would look to the ATF industry (in its present form) as a supplier of technology or major parts for ATF engines.

PRIORITIES FOR NGV R & D IN BRITISH COLUMBIA

Based on information presented in this report, and the consultant's knowledge and experience in the NGV field, the following recommendations are presented.

Conversion Systems: Conversion system development for both spark-ignition and compression-ignition engines merit funding. Funds should be directed to:

(i) Prototype through market development of additional dual fuel conversion systems for diesel engines. Highly desirable, would be projects aimed at developing systems with general applicability to a range of engines (versus a single engine model);

(ii) Conversion of diesel engines to spark-ignition natural gas fuelling;

(iii) Further prototype development and initial market development of second generation ("Gen II"-type microprocessor controlled) systems for spark-ignition engine conversion.

Home Compressors: Development and testing of home compressors should be supported. Compressor sizing should take account of the specific fuel requirements of vehicles for which products are targeted.

Storage: Development of improved storage systems should be encouraged including both non-conventional materials for high pressure storage, and adsorption technology.

Cooperative Funding: Funds should be allocated for either direct contribution or contribution via independent agencies, to enable the province to participate in NGV R & D projects involving multi-source funding. Ensuring provincial co-funding in the CGA's NGV R & D program should be a priority, as it will assist in bringing projects to the province and in maintaining a leading position in terms of the province's expertise in the field.

4.0. Manpower Training

In order to implement new energy technologies into industrial or commercial activities, more trained manpower will be required both at the "shop floor" level and at the "laboratory" level. Although not a direct responsibility of the

B.C.Sc.C. it is obvious that the manpower infrastructure required to carry out R & D in the Province needs to be significantly upgraded. This will require more skilled people at all levels (engineers, scientists, technicians, tradesmen).

A well trained work force will be needed in order to develop and implement new technologies or even upgrade facilities with established procedures. Coal mining is a good example.

New coal mining, processing, and utilization developments in British Columbia are faced with substantial staffing problems, particularly with respect to availability of skilled tradespersons and engineers. Current training facilities and enrolments are inadequate. Therefore, investigation into optimum training programs which would offer the opportunity for maximum employment of B.C. residents and provide a suitable flow of trained persons for industry, is required.

5.0. Environmental

Energy production has become cleaner, safer and more efficient, however much remains to be done. Each source of energy has its own particular brand of environmental and social impact; some with only local implications; others with international implications. As our knowledge increases the understanding of the cost to benefit ratio of each energy technology is improving, but many people would argue that this new understanding is not coming fast enough.

A comprehensive study of this issue is beyond the resources of this committee. Listed below are just four of the many issues that need to be considered:

1. The environment aspects of the use of coal creates both some problems and opportunities. The high sulfur content of Eastern coals may provide an opportunity for B.C. coal to be marketed in Ontario. However in the medium to long term the world may well have to stop burning fossil fuels entirely because of the CO_2 build-up in the atmosphere. The so-called greenhouse effect could already be a serious problem, but at the present time it is hard to prove. In the end coal may only be of value as a chemical feedstock.

2. The use of wood residue for energy should be looked at carefully from the point of view of renewable forests. Should not more of the waste wood be left in the forest to nurture the soil for future generations of trees?

3. The significant advances in making buildings more efficient has now caused what appears to be considerable air quality problems.

4. The lack of suitable fish management techniques for hydro-electric dams has severely constrained the development of what would otherwise be attractive sources of electrical power.

It is becoming clear that environmental concerns must be given a higher weight than in the past, when new energy development is being considered and more R & D

resources be channeled into dealing specifically with or avoiding the pollutants of the energy industry.

6.0. Other Associated Technologies

6.1. Superconductivity

The new materials that are capable of remaining superconducting up to ~100K (liquid nitrogen boils at 77°K) will find many important applications in the next decade. The initial areas of application will probably be in micro-electronics and in specialized superconducting quantum interference detectors (SQUID's) for biological imaging. In the longer term, superconducting motors and magnetic levitation devices could make an impact on energy use planning. There is no reason to consider using superconductivity in the transmission of power unless materials can be found with critical temperatures around 20°C.

6.2. Semiconductors

Research for the preparation of device grade semiconductor materials is not attractive in general at the present time. The market appears substantially saturated. An exception of great importance to B.C. is the Cominco effort in gallium arsenide where they are developing substantial sophistication and at the same time the company produces the raw material, gallium. Amorphous semiconductors may eventually provide a reasonably inexpensive solar cell.

6.3. New Battery Techniques

The development of new battery systems could be an important area for B.C. to emphasize, in part because expertise is currently available (Moli Industries) with a lithium battery and partly because of the improved operation of remote area energy sources such as solar cells or wind turbines[10], batteries are highly desirable for storage. Figure 5.1 from M.L. Sheppard, F.H. Cox, J.P. Chaddick and C.M. Armand, "Introduction to Energy Technology" (Ann Arbor, Michigan 1980), shows a comparison of several types of batteries including a lithium chlorine cell. It is clear that some of the batteries, while not having the specific energy available that fuel cells and internal combustion engines have, produce a considerably higher specific power over the typical fuel cell. Also, some of the batteries such as sodium sulfur and lithium chlorine have a respectable specific energy available. It is clear that any improvement over battery parameters currently available would lead to an immediate market, such as being currently unearthed by Moli Industries. They are developing a single 1.8v cell, weighing 2 kg, which can provide significant power rivaling a lead acid battery, but having much less weight. It is shown by the circled M on figure 5.1.

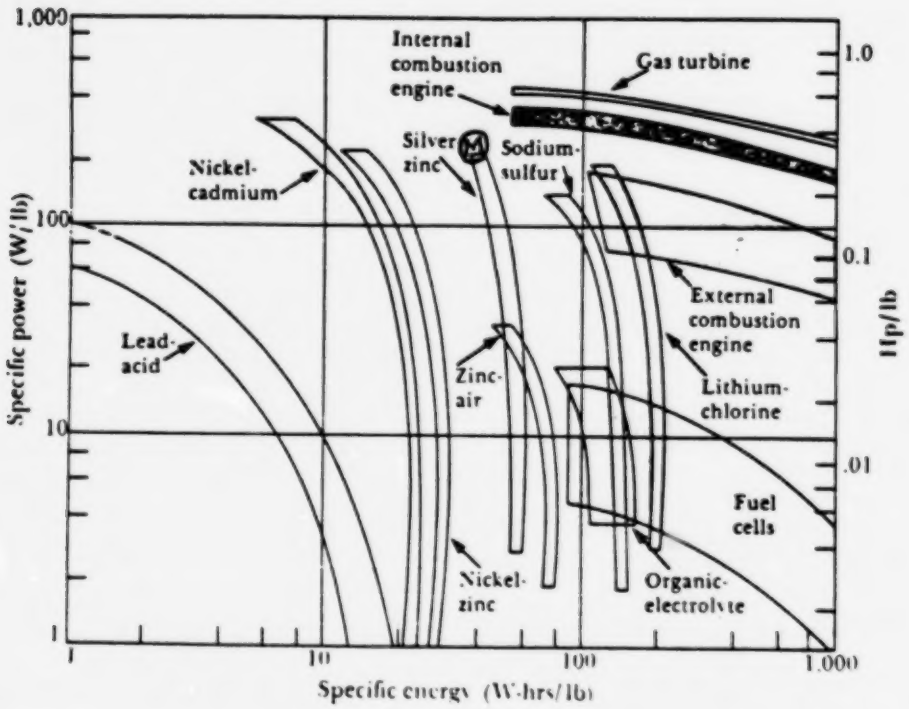

Fig. 5.1. A comparison of the specific power (watts/pound) versus specific energy (watts-hours/pound) for both batteries and combustion engine systems.

6.4. Fuel Cells

The status of the development of various fuel cell technologies may be illustrated by the capacity of the fuel cell stack and its lifetime as indicated on the next page:

	Capacity (Watts)	Life (hours)
Phosphoric Acid	10^2	10^4
Solid Polymer	10	10^4
Alkaline	10	10^4
Molten Carbonate	1	10^3
Solid Oxide	10^{-1}	10^3

The most developed is the phosphoric acid fuel cell (PAFC) technology. Multikilowatt size prototype are undergoing field demonstration; megawatt demonstrators are being tested; multimegawatt commercial prototype units are being designed; and commercialization economics are reaching a decision point. This technology is under major development in the United States for terrestrial applications and may reach commercial status by the end of the decade.

Before this technology can be introduced into a utility system, appropriate technical information, performance data and operating experience is required to determine the effect on a utility system operation and to develop an acceptable level of confidence. Thus there is a need for an operational feasibility and demonstration program for PAFC power plants.

The solid polymer electrolyte fuel cell has been used in space applications where its chief future continues to lie. The extreme sensitivity of the solid polymer electrolyte fuel cell anode to carbon monoxide is the main reason precluding a wider use.

Present development aims at low cost polymer electrolyte and cells which could use low purity hydrogen obtained from commercial fuels. There is a need to develop larger size stacks and to improve cell performance and life.

Alkaline fuel cell technology has achieved application in space programs. Commercialization of this technology will depend on successful operation on hydrocarbon fuels and air, and on resolving the question of the alkaline electrolyte sensitivity to carbon dioxide. Improved electrodes and modules need to be developed and stacks need to be scaled up to multikilowatt sizes.

Molten carbonate is a second generation fuel cell technology. Units are undergoing cell/stack technology development and testing. The possibility exists to develop multikilowatt demonstrators by the end of the decade. Research and development are aimed at overcoming problems such as the sintering of the high surface area anode, dissolution of the cathode loss of electrolyte, material corrosion and mechanical design problems.

Solid oxide fuel cell technology is still at the laboratory research stage of development. The problems of the electrolyte sensitivity and battery formation are being investigated.

There is an opportunity for B.C. to develop and own the advanced fuel cell technology which would stimulate the economic growth and strengthen the

technological base of the Province in the future. R & D should initially aim at a specific market product.

6.5. Hydrogen

Hydrogen is used as an industrial chemical and as an energy carrier. It is not an energy resource but it can provide a method of generating, transmitting and storing energy. Most hydrogen is produced from natural gas and crude oil. It is also produced by electrolysis of water.

Hydrogen can be converted back to electricity using gas turbines or fuel cells. The overall energy efficiency of the conversion electricity-hydrogen-electricity ranges from 25 to 60%. New developments in the electrolysis and fuel cells hold the promise of over 80% efficient conversion.

The transportation costs of hydrogen by pipeline are about one-half of the cost of transportation of electricity by high voltage transmission. The distribution costs of hydrogen from the local substation to residential users are about one-third of the distribution costs of electricity by overhead wire. Thus a long range transportation of energy in the form of hydrogen may be attractive for British Columbia, particularly for northern non-integrated developments. A more detailed cost analysis would be required to assess relative costs of transportation and distribution of hydrogen and electricity for a specified distance and a particular case. The conversion of electricity-hydrogen-electricity also requiress a more detailed assessment.

The problems of a more economic production, storage, transportation, distribution and safety will have to be solved before a large-scale conversion to hydrogen economy could take place. The first major implementation of the hydrogen economy is expected to be in the electric utility off-peak hydrogen production stored for on-peak electricity generation, i.e. the load levelling using fuel cells as generators. Research, development and demonstration of hydrogen production and utilization provide an opportunity for B.C. to develop advanced technologies which could give the Province a competitive advantage in the future. If hydrogen was generally available as an industrial commodity, then it could have significant impact on the synthesis of other high grade fuels, from coal. R & D in Hydrogen based energy technology is a long term venture.

7.0. An Industrial Strategy for B.C.

Between 1976 and 1983, the Province of British Columbia maintained a direct involvement in energy, research and development through the Energy Conservation and Technology. In the first instance the Technology Branch was attached to the British Columbia Energy Commission, however, the responsibility for the Technology Branch was transferred to the Ministry of Energy, Mines and Petroleum Resources in 1978. During this period the Province cooperated with the Federal Government on energy R & D through the Conservation and Renewable Energy Demonstration Agreement (CREDA), a jointly funded program.

In 1983, the Technology Branch was disbanded in a Provincial Government reorganization of energy sector responsibilities and since that time the Provincial Government has had no official energy R & D policy and only a limited number of ad hoc R & D initiatives. The most notable of the ad hoc initiatives were those related to NGV. In the meantime, the Federal Government has persisted with its cooperative programs with Provincial Governments and currently has Memoranda of Understanding (or equivalent) with 8 provinces and the Northwest Territories. The Memoranda of Understanding outlines the cooperative arrangements between the Federal Government funds and the provinces whereby Federal Government funds at the 50 percent or more level energy demonstrations and technology transfer projects.

The Science Council recommends that the Ministry of Energy, Mines and Petroleum Resources make a commitment to energy R & D by directing some portion of their staff and resources to the re-establishment of a Technology Branch with the Ministry and that the Ministry enter into a cooperative arrangement with the Federal Government similar to the arrangement other provinces enjoy with the Federal Government.

There are two distinct initiatives that could make a considerable impact on the Provincial economy:

a) the committee thinks that industry could, with selected investment in new but well established technologies, improve its productivity to an extent that the investment would be paid back in better than 5 years. The coal industry falls into this category and this committee awaits with interest the Bob Granatti study for the Coal Association of Canada.

b) there must be a well established source of information about <u>all</u> aspects of energy so that industries wanting to upgrade their facilities and researchers wanting to help them can have rapid and accurate access to the necessary information.

In order to formulate an industrial strategy for the Province, a thorough understanding of the economics, present technology and probable future directions for energy must be available.

Recommendation 1

That the B.C. Science Council recognize the strategic importance of research and development on natural gas fuelling of vehicles. A short term target is conversion of diesel engines for trucks and urban buses to natural gas. The long term objective would be to lessen the dependence of road, rail and marine vehicles on petroleum-based fuel, and to develop secondary industry for supply of conversion equipment.

The benefits of widespread conversion to natural gas are not only economic but also environmental, and would include not only lower prices for consumers but also increased employment and increased provincial revenues. These benefits can only be realized if development of the fueling station network goes hand in hand with the provision of equipment for engine conversion and control. Thus R & D to improve the required infrastructure should also be of high priority.

A fully integrated collaboration of government, industry and university must be in place for this effort to be successful.

Steps to Implementation:

1. The B.C. Science Council should convene a representative meeting to identify a group of industries, agencies and people who could form a consortium to carry out the necessary work. This consortium would include representatives of the Canadian Gas Association, the Federal Department of Energy, Mines and Resources, the B.C. Ministry of Energy, Mines and Petroleum Resources, the B.C. Research Council, and industries supporting the conversion of vehicles to natural gas fueling.

2. A management planning committee should be formed to identify opportunities and provide preliminary schedules and cost estimates for implementing the specific initiatives.

3. Given interim funds, a project team should be formed to put together a research plan, identifying the various initiatives, schedules, goals, etc. and putting together the applications for funding from the various government and industrial sources.

Recommendation 2

A Centre of Excellence for Energy Studies should be formed in which Industry would play a key part with collaboration from Government and Universities. It could, for example, coordinate cooperation between the funding agencies and provide a reliable source of information about all energy research. A financial commitment from Industry for at least part of the operation is perceived to be necessary for the success of such a Centre. Amongst the activities that this organization could carry out:

(1) Provide a proactive planning centre for energy research, development and demonstration in the Province. Over and above the opportunity of NGV mentioned in recommendation 1, there are some other areas of significant provincial interest:

a) undertake research and development into the other Alternative Transportation Fuels;

b) undertake research in so-called medium and long term areas like Hydrogen and Fuel Cells;

c) provide an overview of the environmental aspects of energy and help identify specific new industrial opportunities for new processes or better controls.

(2) Provide a coherent source of information for all aspects of energy of interest to B.C. The educational benefits of this could be immense. It is possible that the Centre could provide experts to give formal courses of instruction at BCIT, colleges or universities.

(3) Provide a background of information about energy and how it should colour our future industrial strategy for the province. The Centre could provide a market research function to assist in identifying opportunities for new products.

(4) Provide reviews of the latest developments in specific energy fields of potential interest to B.C. and encourage communications between B.C. energy researchers.

(5) Provide space for selected research initiatives. It could be part or all of the site for the NGV initiative mentioned in Recommendation 1.

Steps to Implementation:

1. Form a small steering committee with representatives from industry and university and government. Objective: to identify all the agencies performing energy research and all the industries who might benefit from more up-to-date information.

2. Form an application committee, to prepare the basic constitution, the mission and goals, and the first order operating budget and the necessary space and staffing of the Centre.

3. Identify and recognize as integral members of the Centre all people undertaking bona fide energy research in the Province.

.....con'd

4. Arrange for long term financing from a source of funds, including industries, Federal and Provincial governments, and support in kind from industry and university.

5. Appoint the Director and Administration which would include an Advisory Board representing all the interested parties.

The Province has a large variety of energy sources and problems that provide a unique laboratory for us to become world experts in possibly several niches of the energy technology. Many have already seized this opportunity to become world experts in the energy field. The province not only utilizes this know-how at home but also exports engineering consulting services and energy products all over the world. However, the energy field is changing very quickly: up-to-the-minute information as well as scientific research is required to keep the people and the industries who are involved in the energy field ahead technically and therefore competitive. Research and development in energy can be an "industry" in itself, providing marketable information and technology.

The Centre of Excellence for Energy Studies would also provide the province with the manpower resource that could be applied to solve energy problems quickly if a real emergency arose again. A physical location for this "Centre" would be more attractive than to just have the personnel scattering at other locations, but it would not be essential unless there were some new or expanded R & D effort that was identified to be carried out at this location. A consortium of industries or one industry willing to make a significant commitment would be an essential part of this collaboration.

Recommendation 3

The coal reserves of this province represent a huge legacy which should be exploited intelligently. The use of coal should continually be reassessed as new technologies develop. Consultations with the coal industry will be required for the implementation of coal R & D programs in B.C. Four specific initiatives are identified:

1. Each coal deposit has its own special characteristics. Research into characterization and utilization of the various deposits would improve the marketability of B.C. coals.
2. Research into beneficiation, transportation and handling of coal could lead to improved competition position of B.C. coals on open market.
3. Research into coal combustion, carbonization and conversion could develop new uses of B.C. coals.
4. Environmental research associated with coal industry would lessen the impact of mining and improve the acceptability of coal as a fuel and raw material for process industry.

Steps to Implementation:

1. The Coal Association of Canada has commissioned a report from Bob Granati, to study the present extraction technologies. After this report has been published, a collaborative committee should be formed to identify the specific research aims for the production, marketing and use of B.C. coal.

Recommendation 4

The B.C.Sc.C. should provide a stable long term financial base to support Energy R & D for both strategic research initiatives and curiosity driven research. The strategic initiatives will bring in the shorter term economic benefits, but the support of the curiosity driven research provides an important training ground for the engineers and scientists of the future.

There are many areas of energy research mentioned in this report that should get financial support. Who can predict where the next technological breakthrough will occur - in oil, gas, wood, solar, the so-called new technologies? The only safe prediction is that it will come from a bright individual. He therefore needs to be encouraged to do research. Several examples of this have been cited in this report.

Steps to Implementation:

1. Provide a larger funding base for energy research and explore possible joint collaboration with other agencies and research labs outside B.C.

2. Mount a coherent publicity campaign about energy issues, possibly using the Centre of Excellence for Energy Studies.

3. Cooperate with the educational and industrial communities to provide a coherent manpower infrastructure to broaden energy research.

4. Take a somewhat longer term view as to the viable economic payback for a given research project.

References

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APPENDIX A

Resourcecon Analysis of Home Compressor Prospects

a) Advantages

NGV refuelling currently takes place at a service station and, from the vehicle owner's perspective, is essentially the same as gasoline refuelling. Natural gas-fuelled vehicles, however, generally have only about one-half (or less) the range of their gasoline-fuelled counterparts. As a result, they require much more frequent fuelling, which may pose an unacceptable inconvenience to many motorists.

An alternative approach to refuelling at a service station is refuelling at the vehicle owner's residence on an overnight basis. A small, relatively inexpensive compressor would "slow fill" the vehicle tanks(s) while the automobile is parked overnight in the garage or carport. The home compressor would offer two major advantages over fuelling at a public station.

- Convenience. The requirement to go out of one's way to obtain NGV at a public station would be eliminated, along with the waiting time associated with all types of public fuelling stations. Instead, the motorist would simply connect a fuelling probe, which would fill the car's NGV storage tank(s) overnight.

- Less fuel storage capacity would be required. With the need to carry only one day's fuel supply, one tank would be sufficient for most vehicles, reducing the cost of converting by approximately $500, andmaking NGV economically attractive to a much larger portion of the total vehicle market. In addition, the ability to operate with less fuel storage capacity will require less cargo space to be sacrificed to tankage. This feature will also broaden the appeal of NGV to a larger market segment.

b) Markets

The initial markets for home compressors will be those situations that can expect the best fuel savings. The two markets with the best potential are private automobiles with a steady daily mileage and relatively high annual mileage (commuters), and small commerical vehicle operators.

- Private Automobiles. There are nearly 9 million households in Canada and 82 percent of households own one or more vehicles. Of the 9 million households, 51 percent are single family "owner" dwellings. Natural gas is widely available in Canada -- on a national basis roughly 85 percent of all households have natural gas available. If we define the potential market for home compressors as owned single family dwellings with one or more vehicles with natural gas available, the market is

approximately 3.2 million (9 million x 0.51 x 0.82 x 0.85). The more likely situation is that virtually all single family dwelling owners are also vehicle owners in which case the market is 3.9 million.

- The greater the annual mileage, the greater the total fuel consumption and the lower the natural gas compression costs per litre equivalent. An estimated 33 percent of all Canadian automobiles travel in excess of 12,000 miles per year and 10 percent travel in excess of 18,000 miles per year. Home compressors will be cost effective to high mileage vehicle owners, hence ther are approximately 1.0 to 1.3 million homes in Canada which are the prime market, i.e., owned single family dwellings with natural gas available and with a vehicle use over 12,000 miles per annum.

- Small Commercial Vehicle Operators. Canadian Resourcecon's research has shown that in Canada there are roughly 0.33 commercial vehicles per capita. Sixty percent of commercial vehicles are in fleets of 10 or fewer vehicles with an estimated average of 2.5 vehicles per fleet. The total number of small commercial vehicle operators (from one to 10 vehicles in fleet) in Canada, with natural gas available, is roughly one million. Hence, small commercial fleet operators are another large potential market for the small-scale overnight fuelling compressor.

These market estimates contain information for the Canadian market only. It should be remembered that the home compressor can be sold wherever residential consumers have natural gas service. California, for example, is a market the size of Canada with residential natural gas service and a population heavily dependent on their automobiles.

c) Marketing

The natural gas utilities are the likely marketing channel for a cost-competitive home compressor. Energy conservation, and the attendant decline in natural gas sales per residential customer, have put the natural gas utilities under considerable pressure. For instance, current average natural gas use per residential customer in British Columbia is about 100 GJ per annum; a home compressor supplying fuel for one vehicle would use in the order of 100 GJ per annum, effectively doubling the natural gas use per household. Home compressors would be an excellent business for natural gas utilities; the utilities may want to offer a turn-key package and install the facilities on a lease basis.

It should be noted that natural gas utilities absorb substantial up-front cost in hooking up a new residential customer. In British Columbia, natural gas utilities spend as much as $1,000 per residential customer to provide natural gas to the property line. A typical hook-up cost from the property line to the meter meter is $400, which the utility absorbs. In effect the utility absorbs costs of $1,400 for annual sales of 100 GJ. It is likely that natural gas utilities will be prepared to absorb a portion of the cost of installing a home compressor.

d) Economic Evaluation

The following calculation illustrates the economics associated with the home compressor. The key assumption is that the natural gas utility will absorb the cost of installation and contribute $500 toward the cost of the compressor.

Capital Cost:

Compressor	1,500
Installation (natural gas utility absorbs cost)	-
Subtotal	1,500
Less natural gas utility contribution	500
	$1,000

Annual Cost:

Annualized capital cost @ 12% over 10 years)	$ 177
Annual operating and maintenance	100
	$ 277

Cost per unit of gasoline equivalent for vehicle travelling:

20,000 km/annum @ 13.31/100km - (2,660 litres or 576 gal.)

Compressor cost	$0.10/litre
Natural gas cost	0.14
Total	$0.24

30,000 km/annum @ 13.31/100km - (3,990 litres or 878 gal.)

Compressor cost	$0.07/litre
Natural gas cost	0.14
Total	$0.21/litre

For an automobile owner consuming 2,660 litres of gasoline a year, natural gas provided by a home compression would cost the same as natural gas at the retail station. At higher annual consumption rates, the home compressor beats the retail station cost. Clearly, the key to, and the challenge of, the home compressor market is the development of a reliable, low-cost compressor.

e) Present Status

In the 1970's Rix Industries (California) developed a home compressor design and built a number of prototypes. These prototypes were expensive ($5,000 U.S.+) and the design did not lend itself to cost reduction.

Currently, Sulzer of Switzerland has manufactured 150 copies of a prototype. These units have been sold to natural gas utilities worldwide for extended testing and demonstration. Canadian natural gas utilities have bought 110 of the units at $4,900 each (B.C. Hydro has 10), and 40 units were sold to Australia and New Zealand. It is reported that Sulzer anticipates a selling price of under $2,000 when in commercial production.

One B.C. company, Dynamax Energy Corporation (Paul O'Sullivan et.al.), has been working on a home compressor design and is nearing completion of work on a second generation prototype. Dynamax would hope to achieve a manufacturing cost of $1,000 per unit for volume production.

The Canadian natural gas utilities are proactive vis-a-vis home compressors, as witnessed by their purchase of the Sulzer prototypes, but utilities have been hesitant about mounting their own home compressor design efforts.

APPENDIX B

Companies and Organizations Involved in Conversion System Development

B.C. Research	Contract development and testing of conversion systems with in-house engine lab facilities.
Cryogas Engineering Limited Vancouver, B.C.	Conversion system development and supply for Cummins diesel engines.
FIBA-Canning Ltd. Agincourt, Ontario	Supply of conversion systems and heavy spark-ignition engines.
Fred Holmes Fuel Injection and Turbocharger Specialists Vancouver, B.C.	Contract development of diesel conversion systems.
Mogas Fuel Systems Inc. Vancouver, B.C.	Custom conversion of engines on a contract basis.
Natural Energy Research Ltd. (Paul O'Sullivan) West Vancouver, B.C.	Microprocessor controls for conversion systems.
Ontario Research Foundation Sheridan Park, Ontario	Contract development and testing of conversion systems.
Turbo Resources Fort St. John, B.C.	Conversion of diesel engines to spark ignition.

APPENDIX C

B.C. MARKET ANALYSIS FOR CONSERVATION & RENEWABLE ENERGY BETWEEN 1980 & 1987

CONSERVATION & RENEWABLE ENERGY TECHNOLOGIES

END USE OF POWER	CONSERVATION & RENEWABLE ENERGY TECHNOLOGY & POSSIBLE DEMONSTRATIONS	SUBSECTOR	EMR FUNDING* POSSIBILITIES
Lighting	Light Pipe - Solar - Light Source Vortex Mercury Vapour HPS & Lowe Press Sodium Fluorescence for Incand. Fixtures Low wattage fluor. *Current/Power Limiting devices Photocell Control Timer Control Task Lighting Optimum Switching	Industrial Commercial Residential Institutional	Enerdemo EMTT IERD Class 34
Power to Machine & Equipment	Energy Efficient Electric Motors Variable Speed Drive Motors 2 or 3-Speed Motors	Industrial Commercial Institutional	Enerdemo Class 34 EMTT IERD
Waste Heat Recovery	Air to Air Heat Recovery - Thermal Wheel	Industrial Commercial	Enerdemo Class 34 EMTT IERD
	Flue Gas Exhaust Heat Recovery - To Air: - To Water:	Industrial Commercial	
	High Temp.Industrial Power Ht.Rec. - From Hoods	Industrial	
	Commercial Heat Recovery - Kitchen Exhaust Hoods	Commercial	
Heat Loss/ Gain Prevention	Insulation - Tanks - Pipes - Air Ducts - Equipment - Building Enclosures	Industrial Commercial Residential	Enerdemo Class 34 EMTT IERD

*A brief description of these programs can be found at the end of the table.

Filtering/ Degasifying & Recycling	- Hot Air - Hot Water	Industrial Commercial	Enerdemo Class 34 EMTT IERD
Heat/Cold Storage	Thermal Storage - Hot Water - Mass (Conc. Etc.) - Chilled Water - Ice Banks	Commercial Institutional Residential Buildings	Enerdemo Class 34 EMTT IERD
Vehicle Fuel Use Efficiency	Improved Carburation Break Energy Recovery	Transport - Road	Enerdemo EMTT Class 34
Vehicle Fuel Use Efficiency	*Fuel Additives Propane Conversion	Transport - Road	IERD T.D.C.
Reduced Need for Travelling	Improved Phone/Computer Linkage Highway Speed Limits	Transport - Road; Air	T.D.C. only
Fuel Economy for Swimming Pools	Mechanical Dehumidification Evaporative Cooling VAV Systems	Institutional/ Residential/ Recreational Commercial	IERD Enerdemo EMTT Class 34
Conserving Vehicle Fuel	Conveyor Belt Systems in Place of Vehicle Operations	Mines	Enerdemo IERD
Wood Products Man.	Hog Fuel Pre-Drying	Wood Products Pulp & Paper	Bio Energy Enerdemo Class 34
Conserving Fuel	Energy Efficient Furnaces Energy Efficient Burners	Industrial Commercial	Enerdemo EMTT Class 34
Recovering Thermal Value of Volatiles	Pyrolysis	Industrial	PERD
Providing Only Just Enough Heating/ Cooling at All Times	Control Systems - Load Scheduling/Shedding - Optimum Temp. Selections - Temp./Pressures/Flows	All:	Enerdemo EMTT
To remove Heat/Cold from Air	Heat Pumps	Industrial Commercial Institutional Residential	Solar R & D Enerdemo Class 34

Prevention of Air Movement	Air/Vapour Barriers	Commercial Institutional Residential	Enerdemo R2000
*Lighting	Interior Design for Conservation (Colour) - Window Film - Daylighting	Commercial Institutional Residential	Enerdemo IERD EMTT Class 34
Heating/Cooling	Landscaping - Earth Berming		
Thermal Gradient Elimination	De-Stratification - Air Water	Commercial Institutional Residential	Enerdemo
Electricity	Photovoltaics	Industrial Commercial Residential	Solar R & D Enerdemo
Heat	Solar Collectors - Light - Heat to Air to Water to Anti-Freeze Solar Energy System - Passive - Greenhouses Solar Storage: Plants	 Industrial Commercial Institutional Residential Residential Residential Residential Residential	 Solar R & D Enerdemo Class 34 EMTT
Heat	Bio Gas - From Garbage - From Animal Waste	Industrial Industrial	Bio energy R&D Enerdemo
Provision of	Sails/Windmills - Land - Marine Tidal Power Wave Power Thermal Gradient Salinity Gradient Water Wheels Hydro-Electricity	 Transport-Marine Industrial Marine/Industrial	Solar R & D Bio Energy R&D Class 34 EMTT

IERD: Industry Energy Research & Development; to provide funds to enable industry to develop new technologies in the field of energy conservations. The program is open to all companies incorporated in Canada, trade and resource organizations and consulting firms. The authorized funding level for 1986/87 was $10,000,000.

Class 34: Energy conservation equipment fast write-off; to provide an accelerated tax write-off against corporate income for a range of conservation and renewable energy equipment. Small scale hydro electric generating equipment is included in the list of eligible assets.

Enerdemo: To accelerate, through demonstrations, the adoption and commercialization of energy conservation, oil substitution and alternative energy technologies. The program was terminated in March 1986.

EMTT: Energy Management and Technology Transfer; to assist Canadian enterprises to reduce energy costs, through the dissemination of relevant information via manuals, seminars and workshops.

SUMMARY OF RECOMMENDATIONS

FROM ALL SECTORS

AGRICULTURE AND FOOD PROCESSING

RECOMMENDATIONS (CONT'D.)

- FUNDING FOR SECONDARY MANUFACTURE, FOOD PROCESSING
- RESEARCH ORGANIZATIONS STAFFING AND EQUIPMENT
- GENERAL AWARENESS
- TECHNOLOGY TRANSFER

AQUATIC RESOURCES

$750M INDUSTRY

AQUACULTURE - HIGH GROWTH
- SCIENCE ISSUES

RECOMMENDATIONS

- WATER QUALITY
  - SPECIFIC CONTAMINANTS
  - AQUACULTURE
- AQUATIC INSTRUMENTS AND DEVICES
  - INTERFACE WITH SECTOR
  - GROWTH AREA
- FISH HARVESTING
  - GOVERNMENT AND SOCIAL POLICIES
  - IMPROVEMENTS POSSIBLE
  - SHIP/SHORE COMMUNICATION

AQUATIC RESOURCES

RECOMMENDATIONS (CONT'D.)

- FISH PROCESSING
  - NEW PRODUCTS
  - BY-PRODUCTS
  - QUALITY
  - PACKAGING
- AQUACULTURE
  - INTERFACE WITH BIOTECHNOLOGY
    - DISEASE CONTROL
    - NUTRITION
    - GENETICS
    - WASTE MANAGEMENT
  - NETWORK OF EXCELLENCE

BIOTECHNOLOGY

EMERGING INDUSTRY - $12M

IMPACTS ON MANY SECTORS - FORESTS
- AGRICULTURE
- AQUACULTURE
- HEALTH
- WASTE MANAGEMENT
- MINING

NEED FOR STRATEGIC PLANNING, CO-ORDINATION

RECOMMENDATIONS

- FOCUS ON
  - DISEASE CONTROL
  - GENETIC IMPROVEMENT
  - WASTE MANAGEMENT

- STRATEGIC PLANNING - USE OF EXISTING COMMITTEE

- LONG TERM COMMITMENT OF FUNDING

- RAISE FUNDING FROM $10M TO $30M - 5-10 YEARS

BIOTECHNOLOGY

RECOMMENDATIONS (CONT'D.)

- STRATEGIC RESEARCH, TRAINING, SCHOLARSHIPS
- INDUSTRY/UNIVERSITIES INTERACTION
- REVIEW FACILITIES NEEDS AND CO-ORDINATION

ENERGY

MAJOR RESOURCE OF PROVINCE

DEPENDENCE OF OTHER RESOURCE SECTORS

OIL - IMPORT TO B.C.

NATURAL GAS SURPLUS

RECOMMENDATIONS

- OIL & GAS
  - DEVELOP UNDERSEA ROBOTICS
  - PREPARE FOR SWITCH AWAY FROM OIL
  - NATURAL GAS DIESEL ENGINE CONVERSION
- COAL
  - DEVELOP CAPABILITY TO ANALYZE COALS
  - BENEFICIATION & TRANSPORTATION
  - ALTERNATIVE USES

ENERGY

RECOMMENDATIONS (CONT'D.)

- WOOD RESIDUE AND BIOMASS

  - CONTINUE DEVELOPMENTS - METHANOL, ETHANOL

- OTHERS

  - HYDROGEN
  - FUEL CELL

SCIENCE & TECHNOLOGY ENERGY FOCUS

- CENTRE FOR ENERGY STUDIES
- BUILD EXPERTISE
- UNDERTAKE TESTS
- NATURAL GAS
- LONGER TERM ITEMS

FORESTS AND FOREST PRODUCTS

GROWTH AREA

MOVING TO VALUE ADDED PRODUCTS

RESOURCE DIMINISHING AND MORE EXPENSIVE

WORLD-WIDE COMPETITION

DEPENDENCE ON SCIENCE & TECHNOLOGY

ADVANCED MACHINERY AND SYSTEMS

PEOPLE NEEDS

RECOMMENDATIONS

- OVERALL CO-ORDINATION FOR SCIENCE AND TECHNOLOGY
- ADD VALUE
- IMPROVE PRODUCTION FOR RESOURCE

FORESTS AND FOREST PRODUCTS

RECOMMENDATIONS (CONT'D.)

- RAISE TECHNOLOGICAL AWARENESS AND COMPETENCE
  - RESEARCHERS
  - 'RECEPTORS'
- TECHNOLOGY TRANSFER
- USE OF ADVANCED SYSTEMS, TECHNOLOGIES AND MACHINERY

INFORMATION TECHNOLOGY

$1 BILLION INDUSTRY

11,500 PEOPLE

25%-50% ANNUAL GROWTH

RESOURCE INDUSTRIES/INFORMATION TECHNOLOGY

PEOPLE NEEDS

CO-ORDINATED ACTIONS

RECOMMENDATIONS

- ENHANCE RESOURCE INDUSTRIES BY ENHANCING THE INFORMATION TECHNOLOGY INDUSTRIES
- COMMIT TO INFORMATION TECHNOLOGY
- MARKETING, MANAGEMENT, TECHNICAL PEOPLE
- CO-ORDINATION AND PLANNING ROLE
- INFRASTRUCTURE AND SUPPORT

MANUFACTURING

IMPORTANCE TO PROVINCE

4,000 COMPANIES - 40 LARGE

LACK OF TRAINING

DIFFICULTIES OF LOCATING PARTNERS

TECHNOLOGY TRANSFER - SMALL COMPANIES

RECOMMENDATIONS

- STRATEGIC PLAN - 'CHAMPION'
- BIOMEDICAL DEVICES
- EDUCATION AND TRAINING
- TECHNOLOGY CENTRE
- RESOURCE INDUSTRIES - ROBOTICS
- NETWORKING
- CAD/CAM
- FUNDING

MINING, MINERALS, METALS

NEEDS

- INDUSTRY INVOLVEMENT
- NATIONAL CO-ORDINATION
- FOCUS ON R&D
- RAISING AWARENESS

RECOMMENDATIONS

- R&D CO-ORDINATOR FOCUSSED ON B.C. NEEDS, NATIONAL INTERFACE

- INDUSTRY CHAIRS - ADVANCED MATERIALS

- CENTRES OF EXCELLENCE:

  - ADVANCED MATERIALS
  - INDUSTRIAL MINERALS
  - GEOLOGICAL EXPLORATION
  - RARE & PRECIOUS METALS

EMERGING THEMES

- BUILD ON EXISTING COMPANIES, ORGANIZATIONS AND INDIVIDUALS
- ORGANIZED STIMULATION OF INTERACTION AND PLANNING WITHIN AND BETWEEN SECTORS
- RESOURCE INDUSTRY FOCUSSED, TECHNOLOGY DRIVEN CENTRES OF EXCELLENCE
- VALUE ADDED PRODUCTS FROM RESOURCES USING TECHNOLOGY DEVELOPED IN B.C.
- DEVELOP THE MARKETING, MANAGEMENT AND TECHNICAL TALENTS OF OUR PEOPLE
- EFFECTIVE USE OF SIGNIFICANTLY MORE R&D SPENDING

AGRICULTURE AND FOOD PROCESSING

PRIMARY AGRICULTURE
- ROLE OF AGRICULTURE CANADA
- VERY SMALL AVAILABLE LAND BASE

SECONDARY MANUFACTURE
- POTENTIAL GROWTH AREA

FOOD PROCESSING
- POTENTIAL GROWTH AREA

RECOMMENDATIONS

- INTERFACE WITH BIOTECHNOLOGY
  - DISEASE CONTROL
  - GENETICS
  - WASTE MANAGEMENT
- VALUE ADDED
  - FOOD PROCESSING
- INCREASE PRODUCTIVITY
- INCREASE INDUSTRY INVOLVEMENT
  - CO-OPERATIVE RESEARCH